APPENDIX A

System Characterization Procedure

The tests described in this appendix have been used to provide a preliminary checkout of the control functionality of the prototype ACC system being used in this field operational test. The purpose of these tests is not to measure the specific performance of the ACC sensors per se. Rather, it is to characterize the entire prototype system which includes the sensors, control algorithm, and vehicle platform.

The tests are controlled in reference to the speed of the preceding vehicle. It is desired that the speed of the preceding vehicle be approximately 66 mph or 60 mph in certain tests. In addition, other vehicles should not intervene between the ACC vehicle and the preceding vehicle. If the tests are done without a cooperative preceding vehicle (a confederate vehicle), it will be necessary to accept the speed of an arbitrarily picked preceding vehicle encountered on the highway.

The tests are intended to be useful even if they are performed on normal grades and curves as encountered on limited-access highways. However, curvature and grade will influence quantitative measures of performance to the extent that straight level sections of roadway are desired when consistent numerical results are needed.

The approach employed here for characterizing the ACC system is based upon identifying generic, fundamental tasks that the system may be expected to perform. These tasks are related to the following operational situations:

- closing-in on a preceding vehicle from a long range
- changing to a new headway in response to changing the system's headway setting
- responding to a close approach to a preceding vehicle

This set does not cover all aspects of ACC driving. However, it covers important situations and it provides a good basis for checking the performance of the existing ACC systems.

In order to check and evaluate system performance in these types of situations it is necessary to define (1) the input (essentially the behavior of the preceding vehicle), (2) the initial conditions for starting the test, (3) the conditions that apply during a test run, and (4) the performance signatures and measures used to characterize system performance.

The inputs to these tests are the speed of the preceding vehicle. The results of the tests are based upon measurements of range, range rate, velocity, transmission shift commands, and velocity commands resident within the ACC system. The primary data signals (and their measured equivalents) that are used in performing and evaluating the test results were described in section 2, and illustrated in Figure 3 in the main body of the report. Also, R versus RDot plots are useful for interpreting results [4].

In addition, the computed quantity "Headway Time Margin", symbolized as H,, is useful for interpreting results. The equation for H_{tm} is:

$$H_{tm} = \frac{R}{V} \tag{A-1}$$

In steady following with $V = V_p$, H_{tm} should be equal to the headway time (T_h) used in the headway controller. H_{tm} represents the reaction time within which the following driver would need to match any deceleration profile of the preceding vehicle in order to avoid a crash. The goal of the headway control system is viewed as trying to cause H_{tm} to approach T_h.

Sensor and velocity information is inherent and essential to the performance of this system. Therefore, these data are treated as "measured", to emphasize the potential difference between the real data and that which the sensors report and the algorithm uses for calculations. (Symbols with a subscript "m" identify those variables.)

The following types of tests have been used to characterize basic functional aspects of the system.

A.1 Test 1: Closing-in on a Preceding Vehicle

This test examines the transition from (a) operating in a manner similar to that of a conventional cruise control, to (b) operating in a headway-control mode. When the preceding vehicle is first detected, the ACC vehicle is using V_{set} and not range and range-rate to determine its speed. However, as the ACC vehicle closes in, the headway-control feature is automatically activated. The ACC system slows the vehicle to match the speed of the preceding vehicle and maintains a distance determined by the preselected headway time.

Input

- V_p = 60 mph (88 ft/s, 26.8 m/s)

Initial conditions for the ACC vehicle

- V=70mph(103ft/s,31.3m/s)

- V_{set} =70 mph
- T_h = 1.4 s (implies 123 ft at 60 mph, 37.5 m at 96.6 kph)
- R > about 350 ft (107 m)

Run conditions: Starting from appropriate initial conditions operate the ACC system until a following condition ($V = V_p$ and $R = 1.4\ V_p$) is established.

Example results: Typical results for this test are shown in Figure A-1 and Figure A-2. The process of slowing from the ACC vehicle's initial velocity to V_p is relatively long (30 to 60 seconds). Figure A-1 is a phase plane plot of range versus range rate for this test. Time is not directly shown in this plot, however the direction of increasing time is shown using arrowheads.

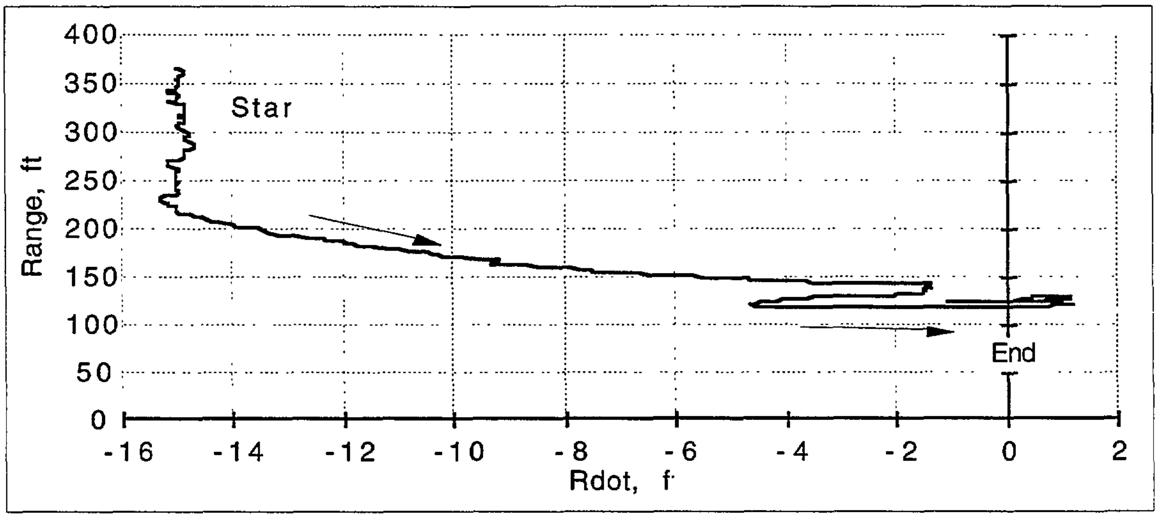

Figure A-1. Range versus Range-Rate, closing from long range

In closing from long range, R decreases as expected. RDot is the derivative of R, and hence is negative for decreasing range.

Figure A-2 is a plot of headway time margin, H_{tm}, versus time during this test. At the beginning of the sequence, before the system starts to respond to the preceding vehicle, the vehicles are separated by more than 3.5 seconds, and H_{tm} decreases linearly. At about H_{tm} = 2.3 seconds, the time history of H_{tm} curves to approach somewhat exponentially to the selected headway time T_h = 1.4 s. Typical variations in speed and grade will cause headway time margin H_{tm} to be within 10 percent of T_h when nominally steady following conditions are reached. Furthermore, the system tends to operate at 1.5 s rather than 1.4 s. (In practice, the actual headway times are best described as 1.1, 1.5, and 2.1 seconds.)

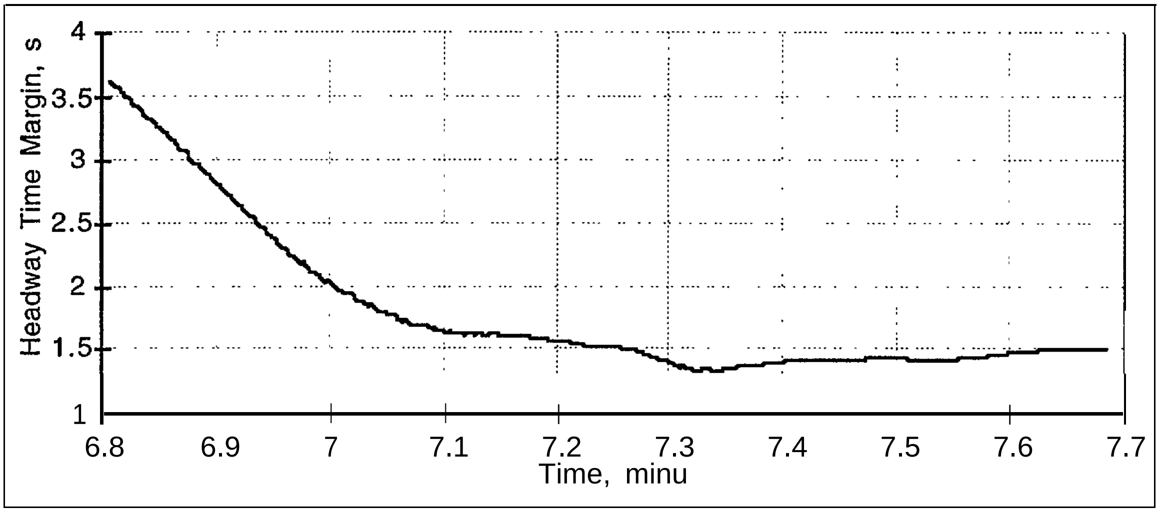

Figure A-2. Headway Time Margin (H_{tm}) versus time, closing from long range

A.2 Test 2: Changing to a new headwav

The purpose of this test is to see how the ACC vehicle responds when headway is adjusted. The vehicle being tested has three settings for headway time: 1.0, 1.4, and 2.0 seconds (see section 3.1.6 in the main body of the report). These settings cover the range of headway used by drivers who tend to travel at the speed of adjacent traffic [6]. The test cases (A through C below) pertain to changes between these levels of headway time.

Case A

Input

- V_p = 66 mph (97 ft./s, 29.5 m/s)
- $\mathbf{T_h}$= 2.0 s

Initial conditions

- V = 66 mph
- V_{set}= 70 mph (103 ft./s, 31.3 m/s)
- R = T_h V_p = 194 ft (59.2 m) for 66 mph

Run conditions: Follow the preceding vehicle for several seconds. (That is, with V = V_p and R = 2.0 V_p.) Change the T_h button setting from 2.0 to 1.0 s. This test should cause the vehicle to change to a shorter range of approximately 97 ft.

Example results: Figure A-3 is a plot of range versus range rate for this test. The range decreases to satisfy the lower T_h selection. Since the velocity of the preceding vehicle is nominally constant, the relative acceleration represents the acceleration of the following ACC vehicle. For this test, the highest closure rate is approximately -6 ft/s (-1.8 m/s) and the total change in range is approximately 120 ft (36m).

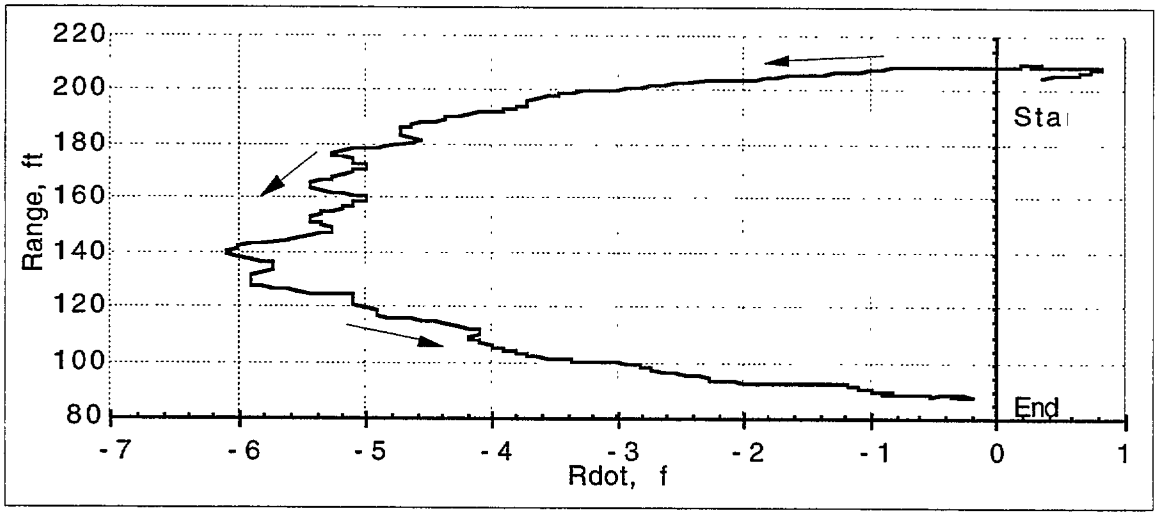

Figure A-3. Range versus Range-Rate, changing from $T_h = 2.0$ to 1.0 s

Figure A-4 shows the headway time margin (see equation (A-1)). The headway time margin changes fairly linearly during the transient with a slope of approximately 3.14 s/minute for this test.

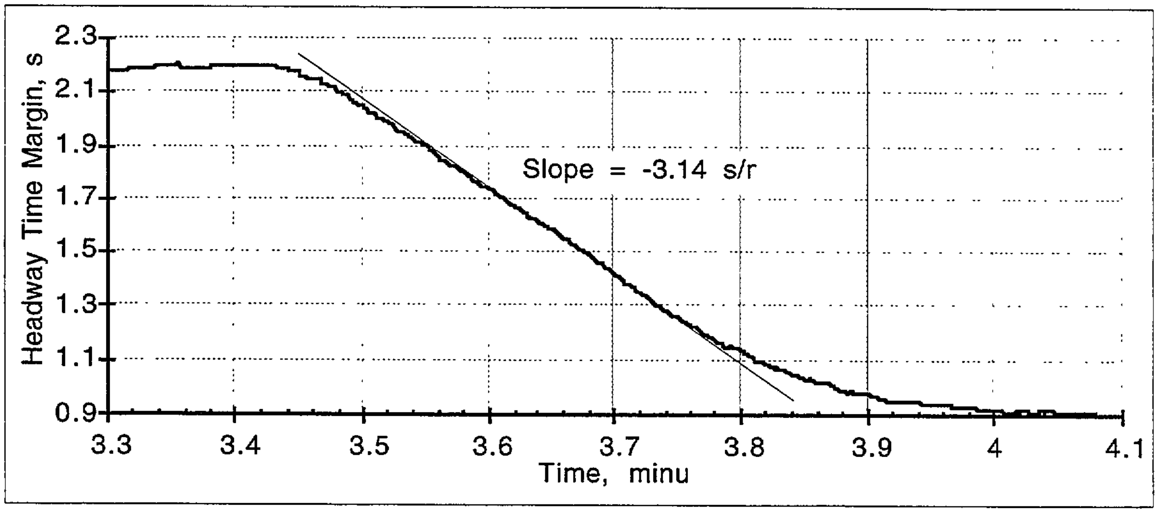

Figure A-4. Headway Time Margin (H_{tm}) versus time, changing from $T_h = 2.0$ to 1.0 s

Case B

(This case is the inverse of case A: initial T_h is 1.0 s and final T_h is 2.0 s)

<u>Input</u>

- $V_p = 66$ mph (97 ft/s, 29.5 m/s)

- T_h = 2.0 s, from T_h = 1.0 s initially

Initial conditions

- V = 66 mph
- V_{set} = 70 mph (103 ft/s, 31.3 m/s)
- R = T_h V_p = 97 ft (29.6 m) for T_h = 1.0 s initially

Run conditions: The same general idea as in case A, except this case causes the vehicle to change from a short to a longer range.

Example results: Figure A-5 presents the range versus range-rate diagram for this example. The maximum range-rate is 8 ft/sec. This means that the ACC vehicle slows down considerably as it widens the headway range by approximately 100 ft (30.5 m) in this case. Examination of the data for cases A and B indicates that this system increased headway (from T_h = 1.0 to 2.0 s) in approximately 1/3 less time than it required to shorten headway by the same increment (compare Figure A-4 and Figure A-6 as well as Figure A-3 and Figure A-5).

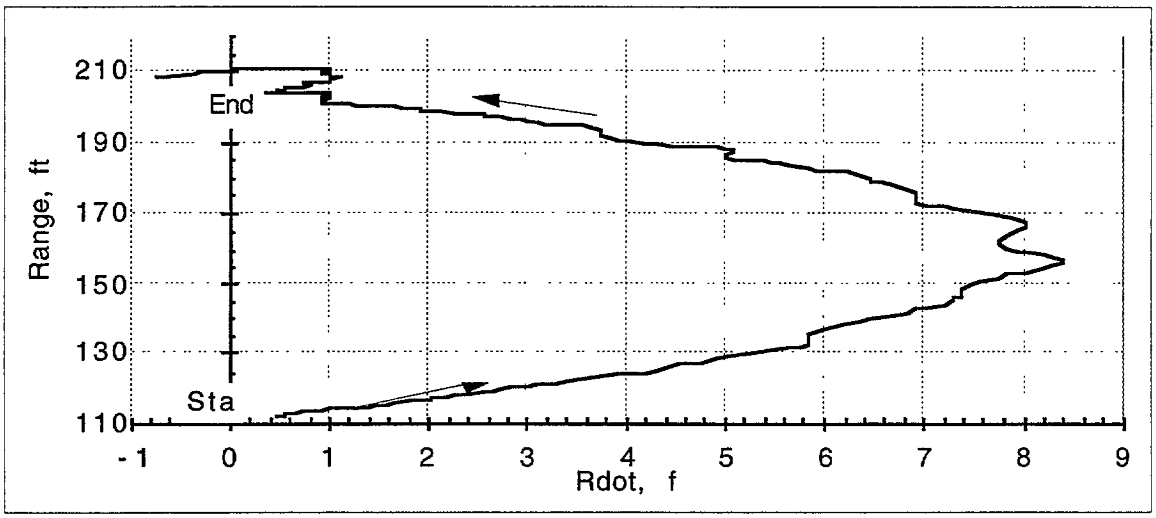

Figure A-5. Range versus Range-Rate, changing from T_h = 1.0 to 2.0 s

Examination of Figure A-6 indicates that the maximum slope of the headway time margin is approximately 6.3 sec/minute, or in other words, the slew rate employed in increasing headway time is about twice as fast as that employed in decreasing headway time.

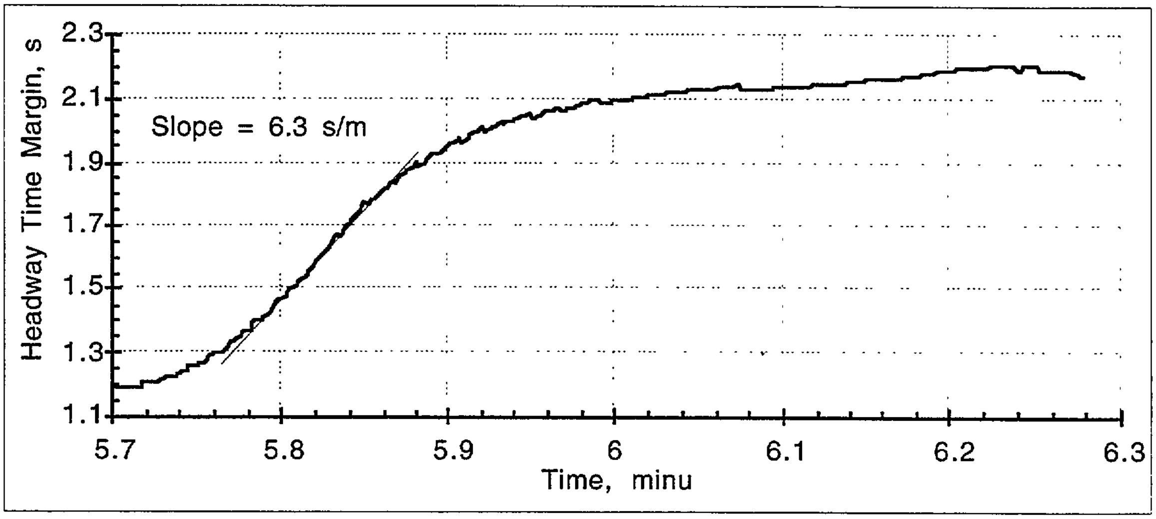

Figure A-6. Headway Time Margin (H_{tm}) versus time, changing from T_h = 1.0 to 2.0 s

Case C

(This case is similar to case A, only that final T_h is 1.4 s)

A.3 Test 3: Manually accelerating

The purpose of this test is to exercise the accelerator pedal override capability as well as to check the ability of the system to correct for a moderately-near encounter. This test may cause the control system to downshift the transmission while the driver is accelerating the ACC vehicle. Nevertheless, once the accelerator pedal is released by the driver, the ACC vehicle should slow down towards a proper following condition in a manner that is characteristic of the operation of this headway control system.

Input:

- V_p = 60 mph

Initial conditions for the ACC vehicle:

- V = 60 mph
- V_{set} = 70 mph
- T_h = 1.4 s (implies T_h V_p = 123 ft)
- The ACC vehicle should be following. (V = V_p and R = 1.4 V_p)

Run Conditions: The driver of the ACC vehicle is to accelerate and partially overtake the preceding vehicle. When the range gets to approximately 2/3 of the original gap, the driver of the following vehicle is to release the accelerator pedal. The test is continued until steady-state following is reestablished or until the driver brakes. (This test could be viewed as an aborted passing maneuver but it is probably better to view it as a means to simulate a near encounter. In practical operation, near encounters can happen for many reasons including merges or other events that cause the sensor to pick up a preceding vehicle for the first time at close range.)

Example results: Data for range versus range-rate are presented in Figure A-7. These data show that the trajectory in the range versus range-rate space is nearly a closed loop. (Ideally it would be a closed loop.) The minimum RDotm is approximately –12 ft/s and the maximum is about 8 ft/s. The minimum range is close to 50 ft.

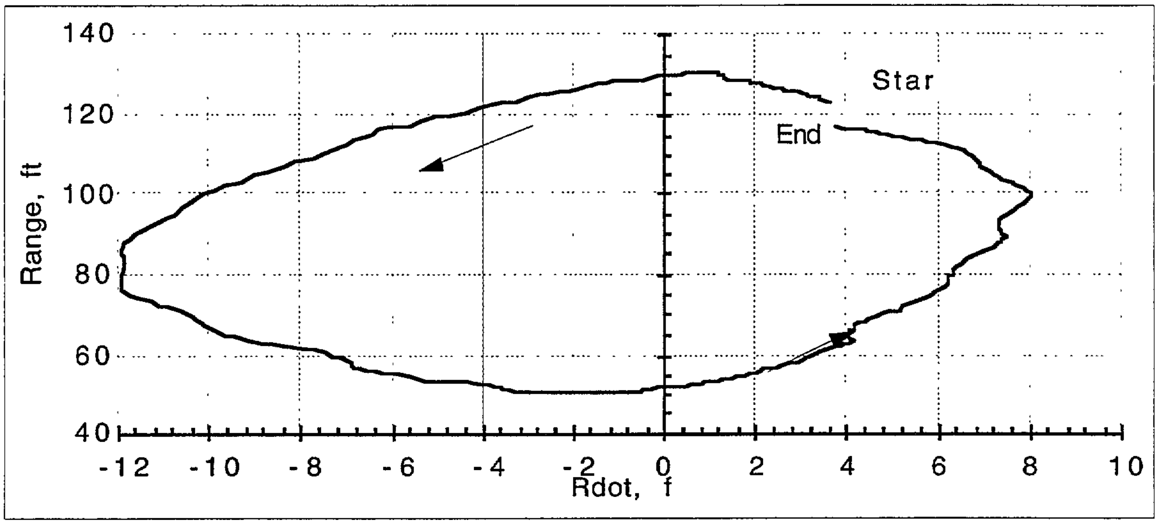

Figure A-7. Range versus Range-Rate, manually accelerating

Figure A-8 shows that the headway time margin goes from about 1.5 seconds to a low of about 0.6 seconds and then back to about 1.4 seconds in this test. This is all done in approximately 0.45 minutes (27 seconds).

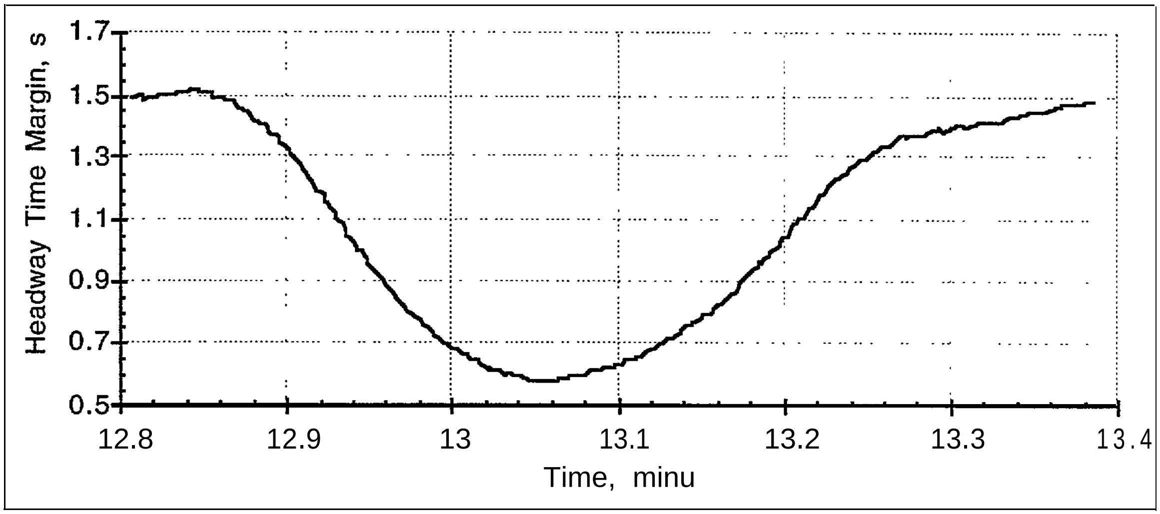

Figure A-8. Headway Time Margin versus time, manually accelerating

The test scenarios presented in this appendix serve as a practicable means for characterizing and periodically reconfirming the performance of the ACC vehicles in the field operational test. They provide performance signatures that can be examined to quantify features that serve as performance measures for ACC vehicles. Since the test conditions do not control for grade and traffic condition, the results will differ from time to time and place to place. Nevertheless, since the functionality of adaptive cruise control does not depend upon high levels of performance from a control system perspective, the results of these tests are sufficient to answer basic questions concerning the control algorithms such as: Does the vehicle slow down when it should? Does the vehicle speed up as it should? Does headway time adjust as it should?

From the characterization tests that were performed, it appears that this ACC system reaches selected headway times with a resolution of approximately ten percent. The system is able to correct for disturbances in speed or range-rate that cause range-rate to reach a closing rate of approximately 10 mph (-15 ft/s, -4.5 m/s). The system is also able to keep the headway time margin above 0.6 seconds in the sudden encounters involved in these tests. Changes in headway time are achieved smoothly with little overshoot or undershoot. When closing in from long range, the ACC system starts to adjust speed at 200 to 300 feet away. And finally, the ACC system downshifts when it needs to achieve a higher deceleration than that available from the natural retardation of the vehicle.

Clearly there are many driving situations that could be tested. The tests described here and an additional test that involves (1) a decelerating preceding vehicle, and (2) a preceding vehicle that suddenly appears in the path of the ACC vehicle, are presented in

[7]. However, tests that involve braking or cut-in are difficult to perform, and could upset other drivers. Such tests were performed as part of the early characterization of the test vehicles, however, they are not part of the current routine checks. The 3 types of tests described in this appendix have been used routinely to check ACC functionality before a test vehicle is released to a participant driver.